TECHNICAL REPORT

on works fulfilled in the fourth quarter according to the Project # 1604
"Research of possibility of semi-conducting $CdGeAs_2$
making by the way of deep impurities doping"

I. Summary of Technical Progress (By task in the Work Plan)

According to the Work Plan under the Project and recommendations of the report for the III quarter, the researches in the IV quarter were directed on a solution of the following tasks:

a) research of influence combined doping of a melt by impurities of copper (acceptor) and indium (donor) on physical properties of obtained $CdGeAs_2$-crystals;

b) research of a possibility of compensating of crystals n-$CdGeAs_2$: In by impurity copper by the way of Cu-diffusion;

c) clearing up of a possibility of growth of crystals $CdSnAs_2$ by the Chohralsii method on the "REDMET-8"-setup.

Besides during the IV quarter initiative additional researches on the following problems were performed.

d) research of influence of doping by impurity gadolinium of crystals $CdGeAs_2$, grown by a HGF-method

e) research of influence of annealing in vapour of volatile components on properties of n- and p-$CdGeAs_2$ with the purpose of obtaining data about a nature of intrinsic defects in this crystal.

In the framework of the above-mention tasks the following works were performed:

1.1. Synthesis of non-doped and doped by indium polycrystalline ingots of $CdGeAs_2$

Synthesis of $CdGeAs_2$-compound was carried out by one-temperature method according to two-step scheme. Technique of synthesis (and the growing) of non-doped and doped $CdGeAs_2$-crystals were similar to this one circumscribed in the Reports on I - II quarters of the given Project. For doping of a melt elementary In of a high purity (99.9999 %) was used . The doping of $CdGeAs_2$ was carried out by introduction of the impurity in charge for synthesis of the compound in the amount of 0.1 weight %. As a result mono-phase polycrystalline ingots of $CdGeAs_2$-compound (without microincludings of second phases) were synthesised. For the purpose of measurements of physical properties of $CdGeAs_2$-crystals the works on growing of monocrystals from obtained synthesised polycrystals were fulfilled. Monocrystals of $CdGeAs_2$ were grown by the Horizontal Gradient Freezing method. The samples cut out from large blocs of material after synthesis without recrystalinsation were also used for a research of electrophysical parameters.

1.2. Measurements of electrophysical properties of monocrystals $CdGeAs_2$ doped by indium

REPORT DOCUMENTATION PAGE

1. REPORT DATE (DD-MM-YYYY)	2. REPORT TYPE	3. DATES COVERED (FROM - TO)
22-01-2001	Final Report	xx-xx-2001 to xx-xx-2001

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Research Of Possibility Of Semi-Conducting CdGeAs2 Making By The Way Of Deep Impurities Doping	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
Unclassified	

6. AUTHOR(S)	5d. PROJECT NUMBER
Voevodine, Valeri G. ;	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME AND ADDRESS	8. PERFORMING ORGANIZATION REPORT NUMBER
Advanced Technologies for Optical Materials (ATOM) 1, Revolution sq., Tomsk 634050 , Russia 634050	

9. SPONSORING/MONITORING AGENCY NAME AND ADDRESS	10. SPONSOR/MONITOR'S ACRONYM(S)
EOARD PSC 802 BOX 14 FPO , 09499-0200	11. SPONSOR/MONITOR'S REPORT NUMBER(S) ISTC 99-7006

12. DISTRIBUTION/AVAILABILITY STATEMENT

A
PUBLIC RELEASE

EOARD
PSC 802 BOX 14

FPO , 09499-0200

13. SUPPLEMENTARY NOTES

14. ABSTRACT

This report results from a contract tasking Advanced Technologies for Optical Materials (ATOM) as follows: The contractor will develop methods of semi-isolating high-resistance CdGeAs2 crystal production by way of control doping by the impurities Cu, Au, Zn, Sc, and Se. Selection of the most promising impurities and optimization of the doping technology will allow minimization of optical loses in CdGeAs2-crystals and related to manufacture of ternary CdGeAs2 crystals with low absorption coefficient for practical purposes of nonlinear optics

15. SUBJECT TERMS

EOARD; Physics; Crystallography

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
Unclassified	Unclassified	Unclassified	Public Release	11	Fenster, Lynn lfenster@dtic.mil
					19b. TELEPHONE NUMBER International Area Code Area Code Telephone Number 703 767-9007 DSN 427-9007

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	22 January 2001	Final Report

4. TITLE AND SUBTITLE

Research Of Possibility Of Semi-conducting CdGeAs2 Making By The Way Of Deep Impurities Doping

5. FUNDING NUMBERS

ISTC Registration No: 1604

6. AUTHOR(S)

Dr. Valeri G. Voevodine

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Advanced Technologies for Optical Materials (ATOM)
1, Revolution sq.,
Tomsk 634050
Russia

8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

EOARD
PSC 802 BOX 14
FPO 09499-0200

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

ISTC 99-7006

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (Maximum 200 words)

This report results from a contract tasking Advanced Technologies for Optical Materials (ATOM) as follows: The contractor will develop methods of semi-isolating high-resistance $CdGeAs_2$ crystal production by way of control doping by the impurities Cu, Au, Zn, Sc, and Se Selection of the most promising impurities and optimization of the doping technology will allow minimization of optical loses in $CdGeAs_2$-crystals and related to manufacture of ternary $CdGeAs_2$ crystals with low absorption coefficient for practical purposes of nonlinear optics

14. SUBJECT TERMS

EOARD, Physics, Crystallography

15. NUMBER OF PAGES

11

16. PRICE CODE

N/A

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19, SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

Measurements of electrophysical properties were carried out on the samples cut from large monocrystal blocks of $CdGeAs_2$. Size of the samples corresponded to (5-10)×(3-5)×(0.5-1.5) mm^3. The contacts were made by fusing In into corresponding points of the sample at temperature 300°C.

The measurements shown that all obtained material of $CdGeAs_2$:In was rather homogeneous as to electrophysical parameters along the volume of the ingots. It is possible to judge about a scatter of values of some electrophysical parameters of obtained $CdGeAs_2$, doped by indium, on data, represented in table 1.

Table 1

Electrophysical parameters of the samples of n-$CdGeAs_2$ doped by indium during synthesis (concentration of In in a melt, N_{In} =0.1 weight %)

Sample	*T*, K	ρ, Om·cm	*n*, cm^{-3}	*m*, $cm^2/V·s$
55	289.5	0.0016	$1.3·10^{18}$	3060
	102.8	0.0016	$1.3·10^{18}$	2980
56	297.5	0.0022	$1.4·10^{18}$	2240
	100	0.0025	$1.3·10^{18}$	1910
57	290	0.00127	$2.8·10^{18}$	1770
	98	0.00128	$2.7·10^{18}$	1780

The presence of indium in a melt during synthesis of the compound improves quality (including homogeneity) of synthesised material and allows to receive crystals of n-type of conductivity with certainty. That is the obtained result testifies to an efficiency of the techniques of obtaining of n-$CdGeAs_2$ by the caring of indium in the melt during $CdGeAs_2$-crystals synthesis.

1.3. Eelectrophysical properties of obtained $CdGeAs_2$ crystals doped by indium and copper

The electrophysical parameters of crystals $CdGeAs_2$, obtained by combined doping by In during synthesis of a material and by Cu during diffusion annealing of $CdGeAs_2$: In, are represented in table 2.

Table 2

Typical values of electrophysical parameters of $CdGeAs_2$, doped by In (In concentration in a melt is 0.1 weight %) and Cu (diffusion annealing of $CdGeAs_2$:In at T=500 ^{O}C, t=48 hours)

Sample	*T*, K	ρ, Om·cm	R, $cm^3/A·s$	*m*, $cm^2/V·s$	Conductivity type

58-2	289	0.02	-30	1460	intrinsic
	80	2.6	+83	32	p

Typical values of electrophysical parameters of obtained $CdGeAs_2$-monocrystals, doped by indium from the melt during synthesis of the material (In concentration in a melt is 0.1 weight %) and doped by copper during recrystallization of a synthesised material by the Horizontal Gradient Freezing method (Cu concentration in a melt is 0.1 weight %) are represented in table 3.

Table 3

Typical values of electrophysical parameters of $CdGeAs_2$, obtained as a result of combined doping of $CdGeAs_2$-crystals from a melt by impurities In and Cu

Sample	Impurity concentration in a melt, weight %	*T*, K	ρ, Om·cm	R, $cm^3/A{\cdot}s$	*n*, cm^{-3}	*m*, $cm^2/V{\cdot}s$	Conductivity type
AB128#65	In:0.1, Cu:0.1	293	0.31	-	$2.97{\cdot}10^{17}$	67	p
		102	0.65	-	$1.1{\cdot}10^{17}$	88	
AB128#63	In:0.1, Cu:0.1	369	0.8	-13.4	-	17	ð
		341	0.96	+18.9	-	20	
		289	1.41	+50.6	-	36	
		90	2.95	+126.6	$\sim 5.{\cdot}10^{16}$	43	
AB128#64	In:0.1, Cu:0.1	291.5	0.05	-	$1.8{\cdot}10^{17}$	720	n+p
		90	0.07	-	$1.8{\cdot}10^{17}$	470	
AB130#66	In:0.1, Cu:0.05	290	2.3	-	$5.{\cdot}10^{16}$	55	p
		100	2.7	-	$2.6{\cdot}10^{16}$	90	

The data represented in tab. 2 and 3 show that effect of compensating of donor impurity In by acceptor impurity Cu is observed, however, considerable increase of a specific resistance of the samples do not happen. As it follows from data represented in the table 1 of the report in the third quarter the specific resistance of the samples of $CdGeAs_2$ after synthesis and recrystallization of a synthesised material without doping or doped by zinc is much more (about 4 Omcm at room temperature and $4{\cdot}10^5$ Om·cm at nitrogen temperature).

Probably in the case of $CdGeAs_2$:In:Cu the specific resistance is such small, because of that created by In and Cu impurity levels are shallow with a small energy of ionisation. That follows from a very small an angle of slope of the dependencies of a logarithm of specific electroconductivity (or concentration of charge carriers) from inverse temperature for $CdGeAs_2$-samples

doped by In and Cu. For example, from the slope of temperature dependence of specific electroconductivity for sample 58-2 values E_1 ~ 0.012 eV and E_2 ~ 0.49 eV are obtained. The value E_2 corresponds to $CdGeAs_2$ forbidden energy gap. The value E_1 is, probably, an energy of ionization of a level, connected with impurity copper.

1.4. Measurements of electrophysical properties of monocrystals $CdGeAs_2$ doped by gadolinium

The doping of $CdGeAs_2$ by gadolinium was fulfilled by introduction of the impurity in charge for synthesis of the compound in the amount of 0.1 weight %. For doping of a melt elementary gadolinium of a high purity (99.9999 %) was used. As a result mono-phase polycrystalline ingots of $CdGeAs_2$-compound were synthesised.

Measurements of electrophysical properties were carried out on the samples cut from large monocrystal blocks of $CdGeAs_2$. Size of the samples corresponded to (5-10)×(3-5)×(0.5-1.5) mm^3. The contacts were made by fusing In.

As well as in the case of In the measurements shown that all obtained material of $CdGeAs_2$:Gd was rather homogeneous as to electrophysical parameters along the volume of the ingots. It is possible to judge about a scatter of values of some electrophysical parameters of obtained $CdGeAs_2$:Gd on data, represented in table 4.

Table 4

Electrophysical parameters of the samples of $CdGeAs_2$ doped by gadolinium during synthesis (concentration of Gd in a melt, N_{Gd} = 0.1 weight %)

Sample	*T*, K	ρ, Om·cm	*n*, cm^{-3}	*m*, cm/V·s	Conductivity type
ANK15#59	295	0.012	$1.8 \cdot 10^{17}$	2720	n
	98	0.015	$1.8 \cdot 10^{17}$	2340	n
ANK15#62	293	0.009	$2.8 \cdot 10^{17}$	2570	n
	94	0.012	$2.8 \cdot 10^{17}$	2000	n

Similarly indium the presence of gadolinium in a melt during synthesis of the compound improves structural quality (including homogeneity) of synthesised material and moves the electrophysical parameters of the samples in the direction of n-type of conductivity. That is gadolinium is an effective donor in the given semiconductor and doping of $CdGeAs_2$ by impurity of gadolinium is efficient method of obtaining electron $CdGeAs_2$.

1.5. Research of effect of annealing in a vapour of volatile components on properties of n- and p-$CdGeAs_2$.

The statement of indicated experiments is connected with carried out by us the preliminary thermodynamic analysis of possible dependencies of a modification of electrophysical parameters of crystals on annealing in the vapour of volatile components (A^2 and C_4^5). The outcomes of

thermodynamic analysis are represented as the scheme in table 5, where the following indications are used. A - acceptors, D - donors, V_A, V_B, V_C - vacancy of the elements A^2, B^4, C^5, respectively; A_i, B_i, C_i - interstitial atoms A^2, B^4, C^5; A_B, A_C, B_A, B_C, C_A, C_B - disorder defects; $\uparrow$ means increase of concentration of defects or of measured magnitude, $\downarrow$ means diminution of concentration of defects or of measured magnitude.

Table 5

The scheme of the correspondence of observable modifications of concentration and mobility of charge carriers to a modification of concentration of intrinsic structural defects at annealing in the vapour of volatile elements A^2 and C_4^5

Annealing in the vapour of	Observation	Possible motive	Concretization
C^5	n - p^- m -	A^-	$A_B{}^-$, $A_C{}^-$, $B_C{}^-$
C^5	n - p^- m^-	D -	B_A - , C_A - , C_B -
C^5	n^- p - m -	D^-	$V_C{}^-$, $A_i{}^-$
C^5	n^- p - m^-	A -	V_A - , C_i -
A^2	n - p^- m -	A^-	$V_A{}^-$, $C_i{}^-$
A^2	n - p^- m^-	D -	V_C - , A_i -
A^2	n^- p - m -	D^-	$B_A{}^-$, $C_A{}^-$, $C_B{}^-$
A^2	n^- p - m^-	A -	A_B -, A_C - , B_C -

The research of effect of annealing in a vapour of volatile components on properties of n- and p-$CdGeAs_2$ was carried out according to the method of "frozen reactions". The initial samples were located in an evacuated ampoules with pure As or Cd. Temperature of annealing was T=500 ^{O}C, time of annealing was 30 + 60 hours, the pressure corresponded to saturation pressure over pure As or Cd at 500 ^{O}C. The results of a modification of electrophysical parameters of n- and p-$CdGeAs_2$ are represented in tab. 6.

Table 6

The results of a modification of electrophysical parameters of n- and p-$CdGeAs_2$ during annealing in a vapour of volatile components (Room temperature)

		Initial properties			Annealing during 30 hours			Annealing during 90 hours		
Vapour	Sample	n, cm^{-3}	m, cm^2/V·s	ρ, Om·cm	n, cm^{-3}	m, cm^2/V·s	ρ, Om·cm	n, cm^{-3}	m, cm^2/V·s	ρ, Om·cm
As_4	29	$+7.2\cdot10^{15}$	290	3.	$-7.6\cdot10^{15}$	2800	0.3	$+1.9\cdot10^{16}$	211	1.6
As_4	30	$+6.5\cdot10^{15}$	230	4.1	$+2.4\cdot10^{16}$	112	2.3	$+1.7\cdot10^{16}$	180	2.1
As_4	54	$+3.1\cdot10^{16}$	90	2.3	$-7.2\cdot10^{15}$	2000	0.4	$+3.4\cdot10^{16}$	50	4
As_4	51-1	$-5.7\cdot10^{17}$	2330	$4.7\cdot10^{-3}$	$-5.3\cdot10^{17}$	2450	$4.9\cdot10^{-3}$	$-4.6\cdot10^{17}$	2350	$5.8\cdot10^{-3}$
As_4	55(In)	$-1.3\cdot10^{18}$	3060	$1.6\cdot10^{-3}$	$-1.3\cdot10^{18}$	1800	$2.7\cdot10^{-3}$	$-1.2\cdot10^{18}$	1600	$3.3\cdot10^{-3}$

Cd	31	$+7.4 \cdot 10^{15}$	160	5.4	$-7 \cdot 10^{15}$	580	1.5	-	-	-
Cd	53	$+3.1 \cdot 10^{16}$	100	2.1	$-3.5 \cdot 10^{16}$	240	0.8	$-2.5 \cdot 10^{16}$	660	0.4

Samples 29, 30, 54: Comparisons of initial properties with the properties obtained as a result of annealing during 90 hours in vapour As_4 shows a decrease of hole mobility and increase of hole concentration. According to the scheme, represented in the table 5, this result may be explained by increase of concentration of Cd-vacancies (acceptors) during annealing in vapour As_4. The result, obtained at the stage of 30 hours, is unexpected and requires repetition of the experiments with more short time stages.

Samples 51-1, 55: Annealing in vapour As_4 of the samples of n-$CdGeAs_2$ (51-1 not doped, 55 doped by In) also shows a modification of concentration of vacancies. Downward tendency of electron concentration with increase of electron mobility is connected with a diminution of concentration of As-vacancies. Downward tendency of electron concentration with diminution of electron mobility is connected with increase of concentration of Cd-vacancies.

Samples 31, 53: Shift of electrophysical parameters in the direction of n-type of conductivity specifies on the fact, that in a case of annealing in vapour of Cd no other intrinsic defects, except vacancies, are exhibited. The increase of electrons concentration at simultaneous increase of mobility of charge carriers corresponds to a decrease of concentration of acceptors Cd-vacancies . The decrease of electrons concentration at simultaneous decrease of mobility of charge carriers corresponds to increase of concentration of the donors As-vacancies.

1.6. Research of a possibility of growth of $CdSnAs_2$ - crystals by the Chohralsii method

The experiments were carried out on the modified setup "REDMET-8", intended for growth of monocrystals of germanium.

At the first stage the basic task was a choice of a composition and a thickness of flux, ensuring preservation of melt composition during a crystallisation. It was found, that when use crucibles from glasscarbon (diameter of 50 mm and height of 40 mm) the satisfactory outcomes can be reached when use eutectic LiCl-$BaCl_2$ by a thickness of 4 - 5 mm as a flux. The experiments on growing of crystals were carried out in an atmosphere of an argon (at pressure 1.1 - 1.2 atm), the velocities of rotation of seed crystal and crucible were 5 turnovers in minute, velocity of an extraction of ingots was 3 mm / hour. It was found, that at these conditions the obtaining of monophase polycrystalline $CdGeAs_2$ ingots of stoichiometric composition with a diameter of 10 - 15 mm and length of 30 - 40 mm is possible. For clearing up of conditions of the obtaining of monocrystalline ingots a prolongation of researches is necessary.

II. Milestones Completed.

2.1. Experiments on doping of crystals $CdGeAs_2$ by impurity In during synthesis for concentration In in a melt 10^{-1} weight % are performed. It is obtained, doping by indium improves a homogeneity of a synthesised material and ensure obtaining crystals of n-type of conductivity. Parameters obtained for $CdGeAs_2$: In at room temperature are the following: $\rho \sim 0.002$ Om·cm, $m \sim 3000\text{-}1700$ $cm^2/V \cdot s$, $n \sim 1\text{-}3 \cdot 10^{18}$ cm^{-3}.

2.2. The electrophysical parameters of crystals $CdGeAs_2$, obtained by combined doping by indium and by copper, were investigated. Doping by Cu fulfilled during recrystalisation of a synthesised material $CdGeAs_2$: In by the Horizontal Gradient Freezing method, and during diffusion annealing with Cu of $CdGeAs_2$: In. It was obtained, that the effect of compensating of donor impurity In by acceptor impurity Cu is observed, however, considerable magnification of a specific resistance of the material does not happen, probably, for the reason of small depth of location of impurity levels in forbidden band.

2.3. Experiments on doping of crystals $CdGeAs_2$ by impurity Gd during synthesis for concentration Gd in a melt 10^{-1} weight % are performed. It is obtained, that presence of Gd in a melt during synthesis of the compound improves a homogeneity of a synthesised material and shift electrophysical parameters of the samples in the direction of n-type of conductivity. Parameters obtained for $CdGeAs_2$: Gd at room temperature: $\rho \sim 0.01$ Om·cm, $m \sim 2700\text{-}2500$ $cm^2/V{\cdot}s$, $n \sim 2\text{-}3{\cdot}10^{17}$ cm^{-3}.

2.4. Work on a research of influence of annealing in vapour of volatile components on properties of n- and p-$CdGeA_2$ is carried out. The obtained data testify about vacancy nature of intrinsic defects in this material. Besides at small times of annealing effect, demanding of a repetition of the experiments for the confirmation and explanation, was observed.

2.5.A potential possibility of growing of crystals $CdSnAs_2$ by the Chohralsii method is shown. One of the important technological tasks at a choice of a composition of a flux for liquid capsulation of $CdGeA_2$ melt is solved.

III. Summary of Personnel Commitments.

Common volume of expenditure of labour in the first quarter corresponds to 150 working days; including

V.G. Voevodin	- 40 w.d.;	A.I. Chernyshov	- 6 w.d.;
Yu.M. Andreev	- 15 w.d.;	O.V. Voevodina	- 16 w.d.;
S.A. Bereznaya	- 40 w.d.;	O.V. Leontieva	- 8 w.d.
Z.V. Korotchenko	- 25 w.d.;		

IV. Major Equipment Acquired

Equipment acquisition at the expense of the Project does not foresee.

V. Description of Significant Travel

Travels at the expense of the Project did not realise.

VI. Current Technical Status (on schedule, behind schedule, ahead of schedule)

Current Technical Status is on schedule.

VII. Delays, Problems, Suggestions

All work, scheduled on the given Project, are carried out in complete volume and in planned period. The series of researches were carried out additionally to the plan within the framework of the common concept of the Project.

The main results of the researches, carried out within the framework of the given project, can be summed up as follows.

7.1. Data on electrical activity of impurities Au, Cu, Zn, In, Sc, Gd when doping the crystals $CdGeAs_2$ from a melt are obtained.

7.1.1. Is defined, that In and Gd are the effective donors with a small energy of ionisation; Cu is an effective acceptor also with a small energy of ionisation; at last, Au, Zn, Sc are the donors with a large energy of ionisation, but ineffective. The maximum values of a specific resistance at room temperature are obtained for $CdGeAs_2$, doped by Au and Sc (up to 9-14 Om·cm). At the temperature of liquid nitrogen the greatest specific resistance are obtained for $CdGeAs_2$, doped by Zn and also for some non-doped crystals (up to $4 \cdot 10^5$ Om·cm).

7.1.2. Maximum solubility of electroactive impurity is observed for Cu and In (about ~ 10^{18} cm-3), a little bit smaller solubility of electroactive impurity is observed for Gd (about ~ 10^{17} cm-3), observable solubility of Au, Zn, Sc had yet smaller magnitude.

7.1.3. The most complete researches were carried out for impurity Cu. The diffusion coefficient of Cu in $CdGeAs_2$ ($D=D_0 \exp(-E/kT)$ when $D_0 = 2 \cdot 10^{-3}$ cm^2/s; E = 0.68 eV) and solubility of Cu in a wide interval of temperatures (for $T < 600\ ^{O}C$ $N = N_0 \exp(-H / kT)$ when $N_0 = 6 \cdot 10^{19}$ cm^{-3}, H = 0.3 eV) were appreciated. The obtained data can be used for purposeful action on parameters of crystals $CdGeAs_2$.

7.2. It was found, that doping by impurities Sc, Gd, In much improves structural performances of growing crystals $CdGeAs_2$, probably, because of clearing of a melt from uncontrollable background impurities. It is rationally to realise additional researches of this effect with the purpose of optimisation of conditions of doping.

7.3. New data on a nature of intrinsic structural defects in the crystals $CdGeAs_2$ are obtained. A prolongation and extension of researches on heat treatment of the crystals $CdGeAs_2$ in the vapour of volatile components (as model experiments for the analysis of processes defect formations in ternary chalcopyrites) is rational.

7.4. Prolongation and extension of work on growing of the crystals $CdGeAs_2$ by the Chohralsii method is rationally also, as this method has a series of advantages in comparison with the Horizontal Gradient Freezing method.

7.5. It is represented rationally to issue the results of carried out researches as the following team-works-publications together with the American colleagues: 1) "The diffusion coefficient and solubility of Cu in the crystals $CdGeAs_2$.", 2) "Doping of the crystals $CdGeAs_2$ from the melt.". After realisation of additional researches getting-up of a paper "The heat treatment and intrinsic structural defects in the crystals $CdGeAs_2$." is possible also.

Project Manager

_ _____ Valeriy G. Voevodin

SPECIFICATION

$CdGeAs_2$-samples for delivery on the Project # 1604

Sample	Impurity	Impurity concentration in a melt, weight %	Type of conductivity	Size, mm	Note
1	undoped		n	6.35×3.0×1.33	recrystallization
2	Au	$1.34 \cdot 10^{-4}$	p	5.95×3.1×1.25	synthesis
3	Au	$8.1 \cdot 10^{-4}$	n	7.05×4.8×1.35	synthesis
4	Au	$8.1 \cdot 10^{-4}$	p	5.7×4.6×1.32	recrystallization
5	Au	$1.0 \cdot 10^{-2}$	n	4.9×4.75×0.99	synthesis
6	Au	$1.0 \cdot 10^{-1}$	p	6.0×3.5×1.35	recrystallization
7	Sc	$1.0 \cdot 10^{-3}$	p	5.1×5.1×0.66	synthesis
8	Sc	$1.0 \cdot 10^{-2}$	n	5.4×4.9×0.78	synthesis
9	Sc	$1.0 \cdot 10^{-2}$	p	6.2×5.4×0.89	synthesis
10	Sc	$1.0 \cdot 10^{-1}$	n	5.75×5.2×0.91	synthesis
11	Sc	$1.0 \cdot 10^{-1}$	p	6.1×5.5×1.07	synthesis
12	Cu	$1.0 \cdot 10^{-1}$	p	6.65×3.7×1.12	synthesis
13	Cu	diffusion, 450^{O}C, 30 hours	p	5.5×5.45×0.67	recrystallization
14	Cu	diffusion, 550^{O}C, 87 hours	p	5.7×5.55×0.88	recrystallization
15	Zn	$1.0 \cdot 10^{-2}$	p	3.75×3.7×0.83	synthesis
16	Zn	$1.0 \cdot 10^{-2}$	n + p	9.5×4.0×1.64	recrystallization
17	Zn	$1.0 \cdot 10^{-1}$	p	7.15×2.715×0.98	synthesis
18	Zn	$5.0 \cdot 10^{-1}$	n + p	8.3×4.25×1.16	recrystallization
19	Zn	1.0	n + p	6.4×3.5×1.1	recrystallization
20	In	$1.0 \cdot 10^{-1}$	n	4.1×4.0×1.12	synthesis
21	Gd	$1.0 \cdot 10^{-1}$	n	4.9×4.75×0.74	synthesis
22	In/Cu	0.1 / 0.1	p	5.2×2.85×1.15	recrystallization

23	In/Cu	0.1 / 0.05	p	5.3×2.75×0.98	recrystallization

FINAL REPORT ADDENDUM

QUESTIONS & RESPONSES

(Based on communications at contract completion between
Air Force laboratory representatives and the contractor, January 2001.)

Q1. On the samples, what is meant by Synthesis vs. Recrystalization?

A1. Here these words concern to the genesis of ingots, namely: a) we used a term "Synthesis" if the processes of synthesis and following next crystallization were carried out in one technological cycle, without re-charge of the container; b) the term "Recrystallization" was used when we carried out repeated crystallization of a synthesized material (above named as "Synthesis"!) for deriving of monocrystals.

Q2: Is the impurity concentration the amount of impurity added to the initial charge or the impurity content of the final boule measured by some other unspecified method? If the latter, what is the method?

A2. The former is true. Generally, we had a possibility to carry out direct measurements of the impurity content in CGA here in Tomsk, but the expenditures on these measurements were not stipulated in the estimate of the given contract.